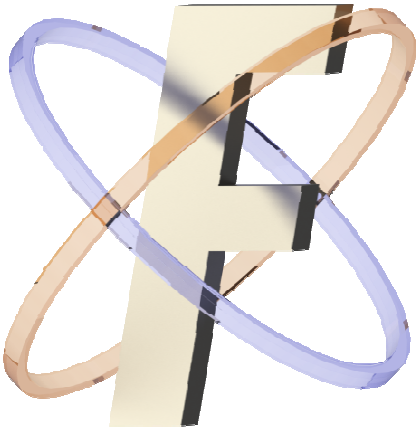
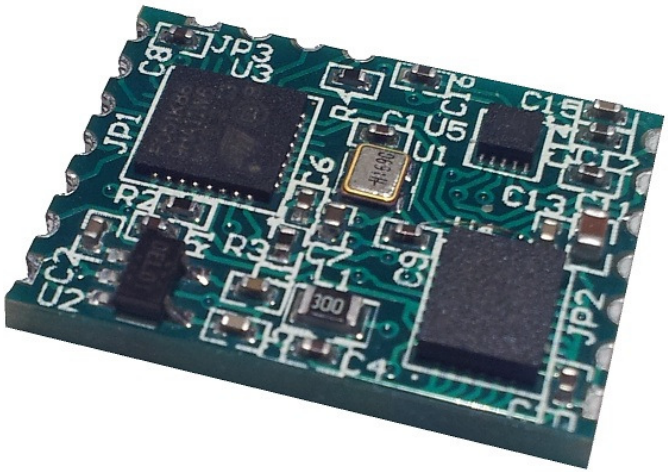


µFusion

User Manual



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1. Introduction

µFusion is an easy configurable 9DoF AHRS system which mixes data coming from 3 axes accelerometer, 3 axes gyroscope, 3 axes magnetometer to extract Attitude and Heading References. Thanks to its shape, weight and small dimensions, it can be easily embedded on every kind PCB.
µFusion offers a range of communication interface options that includes UART, SPI and USB 2.0[1] with which is possible to have access to several I/O registers for configuration and data output.
Every µFusion is individually factory calibrated but provide the functionality to be recalibrated when mounted on the final product.

1.1. Applications

· Helicopters, quadrotors and flying UAV
· Underwater vehicles
· Camera stabilization
· Balancing robots
· Gaming and virtual reality
· Compensated compass
· Position detection
· Motion capture
· Robot navigation / SLAM
· Antenna control

2. Specification

Electrical characteristics

Symbol	Parameter	Test condition	Min	Typical	Max	Unit
V_{dd}	Supply voltage		3.2	5	6	V
I_{dd}	Current consumption	Vdd = 5V		23		mA
$V_{IH(UART)}$	Digital high level input voltage (UART)		1.7		5.5	V
$V_{IL(UART)}$	Digital low level input voltage (UART)		-0.3		0.9	V
$V_{IH(SPI)}$	Digital high level input voltage (SPI)		1.8		3.3	V
$V_{IL(SPI)}$	Digital low level input voltage (SPI)		-0.3		0.9	V
V_{OH}	High level output voltage		2.4	3.0	3.2	V
V_{OL}	Low level output voltage				0.4	V
T_{on}	Turn on time			0.8		s
f_{UART}	UART communication frequency		115200	115200	921600	baud/s
f_{SPI}	SPI communication frequency				16	Mbit/s

[1] USB 2.0 is available only through the motherboard.

Mechanical characteristics

Symbol	Parameter	Test condiction	Min	Typical	Max	Unit
Dim	Dimensions			15x20		mm^2
W	Weight			3		g
A_Y	Static accuracy (Yaw)			1.5		°
$A_{R,P}$	Static accuracy (Roll, Pitch)			0.5		°
f_{out}	Maximum output rate			190		Hz
T_{range}	Operating temperature range		-20	20	60	°C
ω_{max}	Maximum angular velocity				2000	°/s

3. µFusion pinout

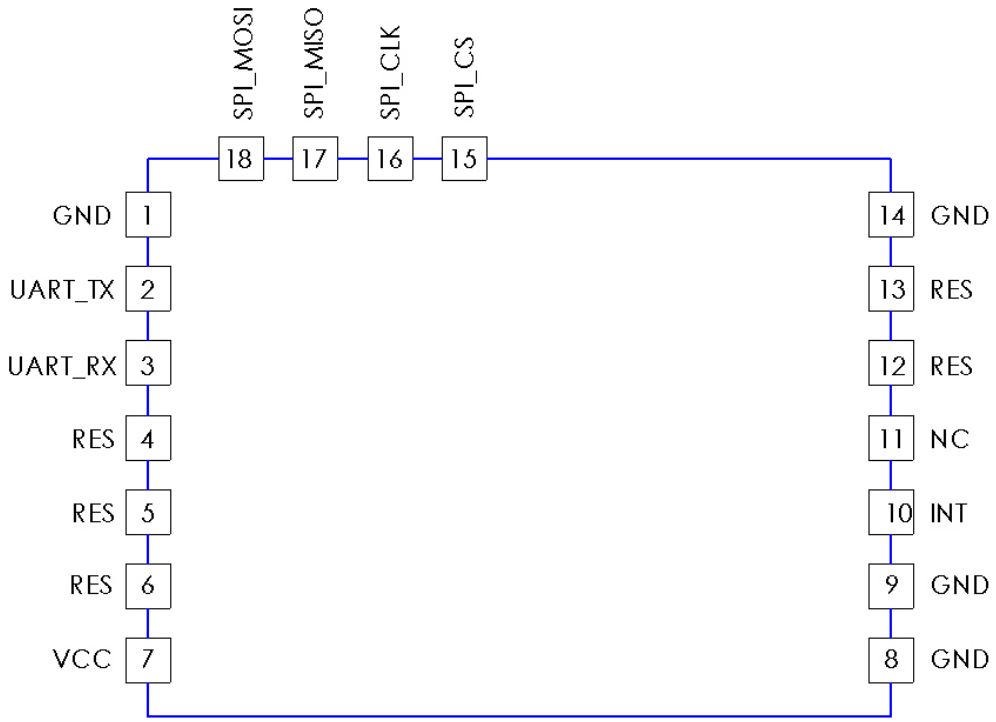

Figure 1. µFusion pinout.

Pin	Name	Description
1	GND	Ground.
2	UART_TX	TTL Uart trasmitter.
3	UART_RX	TTL Uart receiver.
4	RES	Reserved. Leave pin floating.
5	RES	Reserved. Leave pin floating.
6	RES	Reserved. Leave pin floating.
7	VCC	Power supply.
8	GND	Ground.
9	GND	Ground.
10	INT	Interrupt.
11	NC	Not connected. Leave pin floating.
12	RES	Reserved. Leave pin floating.
13	RES	Reserved. Leave pin floating.
14	GND	Ground.

15	SPI_CS	SPI chip select (0: SPI communications, 1: UART communications). This pin is 5V tolerant.
16	SPI_CLK	SPI clock.
17	SPI_MISO	SPI serial data output.
18	SPI_MOSI	SPI serial data input.

4. Engine description

µFusion works as an Attitude and Heading References System. It uses a Kalman filter, that takes accelerometer, gyroscope and magnetometer data as input, in order to estimate a drift-free attitude reference in a 360° 3D space with high accuracy in both static and dynamic conditions. The Kalman filter runs in a 32-bit ARM processor at the frequency of 190Hz.
Accelerometer, gyroscope and magnetometer are factory calibrated, but run-time calibrations for magnetometer and gyroscope are provided. Gyroscope biases are automatically calibrated during the normal operations of the engine, while magnetic calibration is active only when selected by the specific register.

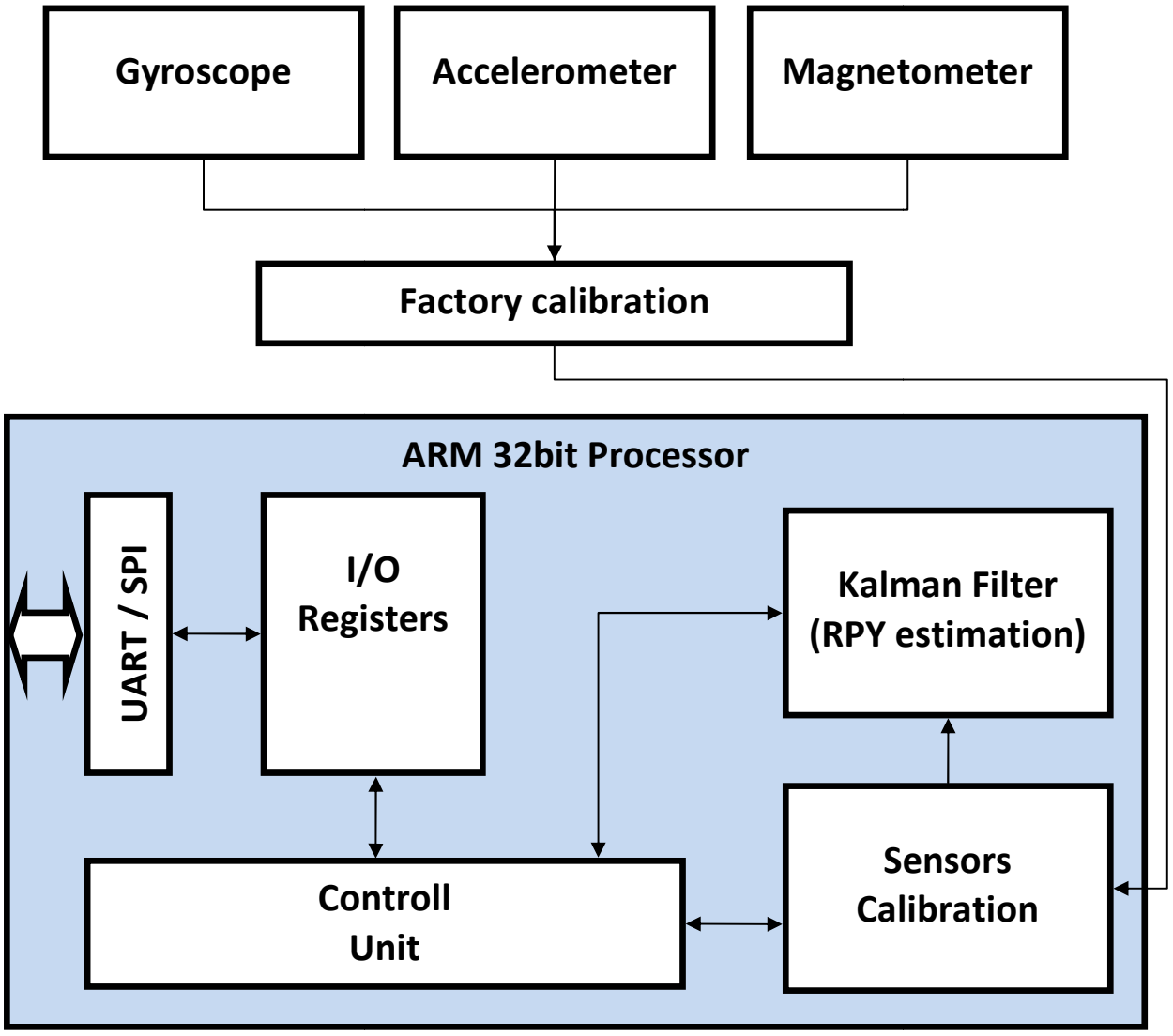

Figure 2. µFusion high level schematic.

1.2. Axis assignment

µFusion uses the ENU (East, North, Up) fixed reference system. In this representation, the X axis points to East, the Y axis points to North and the Z axis points Up. Every output rotation is expressed according to this reference.
In Figure 3 it is shown how this representation has been fixed on µFusion.

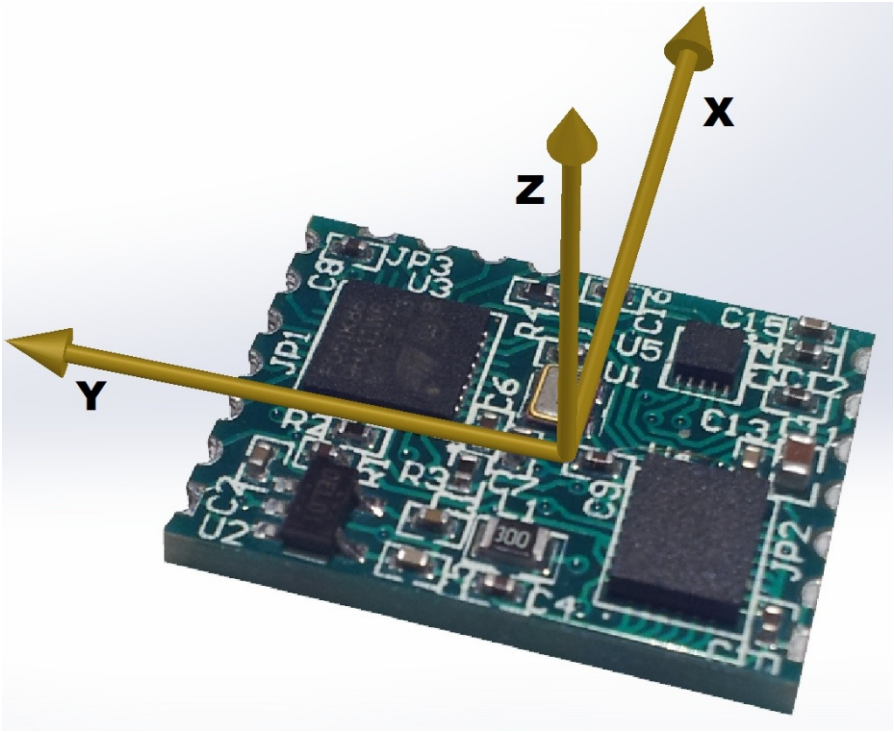

Figure 3.µFusion axis assignement

1.3. Factory calibration

The data coming from the three sensors are not usable as soon as acquired. Thess measures are affected by different types of errors. Two main errors affect mostly the real measured value: offset and scale factor. Offset is the constant error between the measured value and the known value (typically the 0), whereas the scale factor represents the variation of the during the increase of the distance from the zero. So it's possible to assume that:

$$V_{real} = offset + scale \cdot V_{meas}$$

where V_{real} is the real value and V_{meas} is the measured value. For every sensor, the values of *offset* and *scale* are estimated during the factory calibration process, stored into µFusion and applied for every acquisition.

1.4. Magnetometer calibration

Any magnetic sensor is influenced by hard-iron and soft-iron interferences.
Hard-iron interference is due to permanent magnets or magnetized iron and steel, that are present around the sensor and create a magnetic field that is added directly to the Earth's magnetic field.
Soft-iron interference is caused by all the items around the magnetometer which are composed by iron material which distorts the direction of the Earth's magnetic field.
In order to obtain better results in the Heading estimation, these two factor have to be compensated. The algorithm running on µFusion allows to compensate these distortions and provides a magnetometer calibration to estimate them.

When µFusion is placed in a new system, it's highly suggested to run at least once the magnetometer calibration. To run the calibration, just set to 1 the M_CAL of the CTRL_REG_1 and rotate the entire system, preferably as if you were tracing some eight-shapes in the air. After the calibration is completed, the bit M_CAL is automatically set to 0.

5. Communication

The interface with the board is composed by several I/O registers which allow to set the desired configuration and acquire the output values. You can access to these registers can be done through the UART and the SPI interfaces. In the sections below, it is described how to have access to the I/O registers.

1.5. UART

µFusion permits to communicate through the universal asynchronous receiver/transmitter (UART) and uses a communication protocol to read and write the I/O registers. The interface uses two lines: Tx serial input and Rx serial output. The Tx high output voltage is at 3.0 V and the Rx input accepts voltage from 1.7V to 5.5V.
The UART interface uses 8N1 (8 data bits, no parity, 1 stop bit) format and supports the following standard baud rates: 115200, 230400, 460800, 921600. The default baud rates is set to 115200 and can be changed by using the CTRL_REG1.
At the beginning, µFusion works as slave waiting for a command. There are two types of commands that µFusion accept: register write command and register read command. These two commands allow to read and write I/O register.
The read command starts with the hash symbol "#" followed by "R", the number of the register in ASCII format and the number of consecutive register to be read that is also in ASCII format:

#	R	Number of register	Consecutive

the value of Number of register and Consecutive are always expressed by two characters.
The answer to this command is the following:

#	R	Value 1	Value 2	Value…

where Value 1, Value 2, etc… are the binary values requested by the read command.
The write command starts with the hash symbol "#" followed by "W" and the number of the register in ASCII format:

#	W	Number of register	Value

the value of Number of register and Value are always expressed by two characters.

1.6. SPI

The SPI (Serial Peripheral Interface) is a synchronous serial communication standard that is commonly supported by many micro-controllers and other embedded systems. The SPI standard defines 4 different working modes, µFusion uses the Mode 3.
The SPI interface uses four lines: MISO (master input slave output), MOSI (master output slave input), CLK (clock) and CS (chip select). The maximum voltage accepted by the four lines is 3.3V. SPI read/write operations are completed in 16 or more clock cycles. The first byte is sent from the master to µFusion and contains the address of the register and the following bytes containing the register data. The first bit of the register address is the R/$\overline{W}$ bit and it is used to indicate the Read (1) or Write (0) operation. During the data transmission, the big endian convention is used.

Figure 4 **Errore. L'origine riferimento non è stata trovata.** and Figure 5 show respectively examples of reading and multireading operations, while Figure 6 shows an example of writing operation.

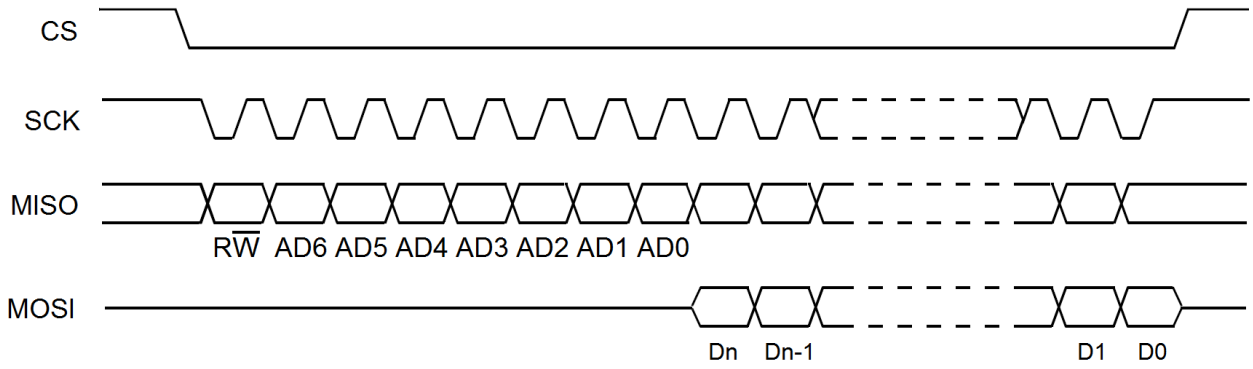

Figure 4. SPI reading.

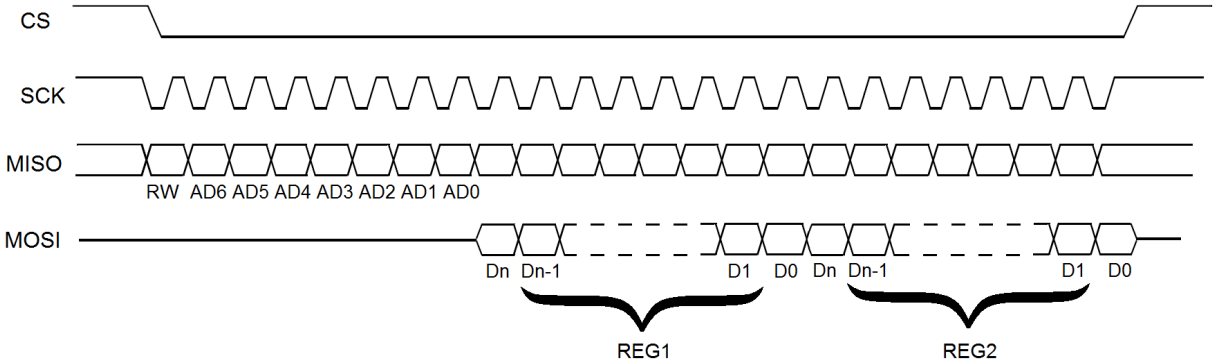

Figure 5. SPI multireading.

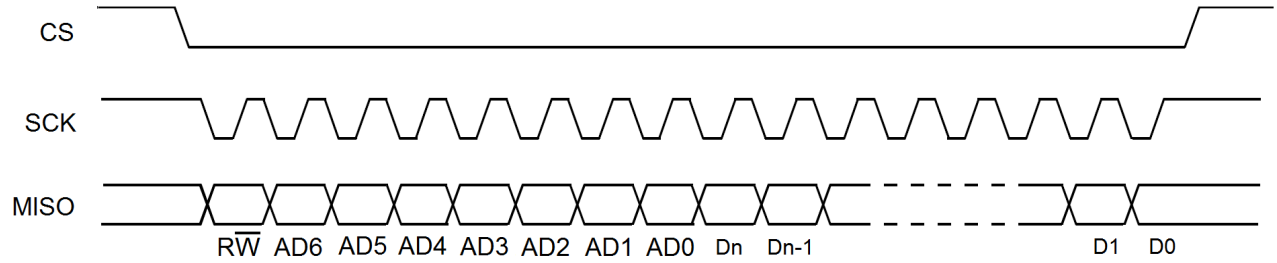

Figure 6. SPI writing.

To avoid communications problems, some time constrain have to be respected.

Symbol	Parameter	Min	Max	Unit
T_{comm}	Time between two SPI communications.	3		µs
T_{byte}	Time between two	8		µs

6. µFusion Registers Description

WHO_AM_I (8 bit)

Who am I.

Address: 0x00.

WHO_AM_I

WHO_AM_I	0xA5

CTRL_REG1 (8 bit)

Control register 1.

Address: 0x01. Default: 0xC8.

PW	M_EN	M_CAL	M_CAL_RES	INT_DRDY	UART_SP1	UART_SP2	

PW	Power Mode. Default: 1 0: Power down 1: Power on
M_EN	Magnetometer enable. Default: 1. 0: Magnetometer disabled. 1: Magnetometer Enabled.
M_CAL	Magnetometer calibration. When this bit is set to 1, the magnetometer calibration starts running. When the magnetometer calibration is stopped, this bit is automatically set to 0. Default: 0. 0: Magnetometer calibration is not running. 1: Magnetometer calibration is running.
M_CAL_RES	Magnetometer calibration result. At the end of the magnetometer calibration, if this bit is set to 1 it is successful and 0 otherwise.
INT_DRDY	Interrupt activation an INT1 pin when a new data is ready. Interrupt is active high. Default: 1. 0: Interrupt disabled. 1: Interrupt enabled.
UART_SP1 UART_SP2	UART communication speed. As soon as the value of these registers has changed, the UART starts to communicate with the new speed.

UART_SP1	UART_SP2	Speed (Baud/s)
0	0	115200
0	1	230400
1	0	460800
1	1	921600

CTRL_REG2 (8 bit)

Control register 2.

Address: 0x02. Default: 0x00.

CQ_SEND	CKS_SEND	CRPY_SEND	0	0	0	F_OUT1	F_OUT2

CQ_SEND	Continues quaternion sending. When this bit is set, µFusion sends automatically via UART the four quaternions as soon as updated. This function is not available during SPI communications.
CKS_SEND	When CQ_SEND = 1 and this bit is set to 1, also the quaternions checksum is automatically sent.
CRPY_SEND	Continues RPY sending. When this bit is set, µFusion sends automatically via UART the Roll, Pitch and Yaw as soon as updated. This function is not available during SPI communications.

F_OUT1 F_OUT2	Output data rate. This bits are used only when CQ_SEND or CRPY_SEND are set.

F_OUT1	F_OUT2	Freq (Hz)
0	0	190
0	1	95
1	0	50
1	1	25

ACC_NUMBER_AVG (8 bit)

Number of average applied on the accelerometer raw data.
Address: 0x08. Default: 0x01.

N_AVG_ACC

N_AVG_ACC	Number of average value represented as unsigned integer.

GYRO_NUMBER_AVG (8 bit)

Number of average applied on the gyroscope raw data.
Address: 0x09. Default: 0x01.

N_AVG

N_AVG_GYRO	Number of average value represented as unsigned integer.

MAG_NUMBER_AVG (8 bit)

Number of average applied on the magnetometer raw data.
Address: 0x0A. Default: 0x01.

N_AVG

N_AVG_MAG	Number of average value represented as unsigned integer.

FLOAT_FIXED_REGISTER (32 bit)

Fixed float register. This register contains a fixed value and can be useful to set the right method to acquire data.
Address: 0x10.

FLOAT_FIXED_REGISTER

FLOAT_FIXED_REGISTER	-9854.328125 (-9854,215)

OUT_Q1 (32 bit)

Value of quaternion 1.
Address: 0x11.

OUT_Q1

OUT_Q1	Quaternion value represented as floating point.

OUT_Q2 (32 bit)

Value of quaternion 2.
Address: 0x12.

OUT_Q2

OUT_Q2	Quaternion value represented as floating point.

OUT_Q3 (32 bit)

Value of quaternion 3.
Address: 0x13.

OUT_Q3

OUT_Q3	Quaternion value represented as floating point.

OUT_Q4 (32 bit)

Value of quaternion 4.
Address: 0x14.

OUT_Q4

OUT_Q4	Quaternion value in floating point.

OUT_Q_CHECKSUM (32 bit)

Value of quaternion checksum.
Address: 0x15.

OUT_Q_CS

OUT_Q_CS	Checksum for the values of the four quaternions. It is calculated as the xor of the four quaternion values.

OUT_ROLL (32 bit)

Value of roll angle in degree.
Address: 0x16.

OUT_ROLL

OUT_ROLL	Roll value represented as floating point.

OUT_PITCH (32 bit)

Value of pitch angle in degree.
Address: 0x17.

OUT_PITCH

OUT_PITCH	Pitch value represented as floating point.

OUT_YAW (32 bit)

Value of yaw angle in degree.
Address: 0x18.

OUT_YAW

OUT_YAW	Yaw value represented as floating point.

OUT_RPY_CHECKSUM (32 bit)

Value of RPY checksum.
Address: 0x19.

OUT_RPY_CS

OUT_RPY_CS	Checksum for the values of roll, pitch and yaw. It is calculated as the xor of the three RPY values.

OUT_ROLL_VEL(32 bit)

Value of roll velocity in degree.
Address: 0x1A.

OUT_ROLL_VEL

OUT_ROLL_VEL	Roll velocity value represented as floating point.

OUT_PITCH_VEL (32 bit)

Value of pitch velocity in degree.
Address: 0x1B.

OUT_PITCH_VEL

OUT_PITCH_VEL	Pitch velocity value represented as floating point.

OUT_YAW_VEL(32 bit)

Value of yaw velocity in degree.
Address: 0x1C.

OUT_YAW_VEL

OUT_YAW_VEL	Yaw velocity value represented as floating point.

7. µFusion suggested land pattern

Figure 7 shows the recommended land pattern, all the quotes are expressed in mm.

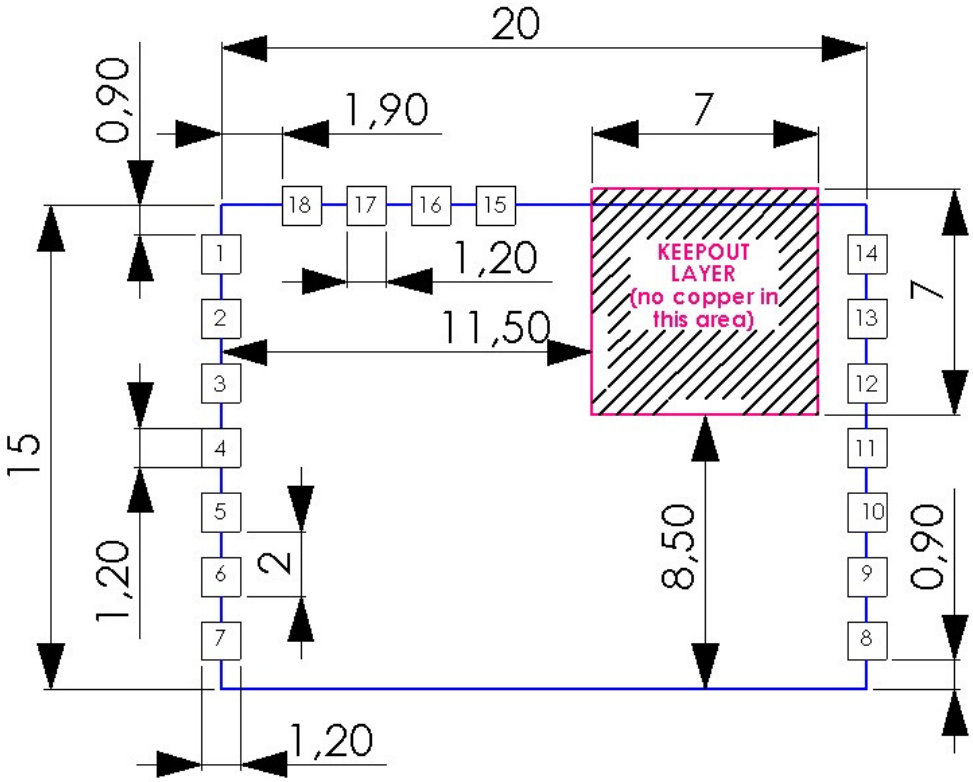

Figure 7. Suggested land pattern.